4D HAMMER Image Registration Method for Longitudinal Study of Brain Changes

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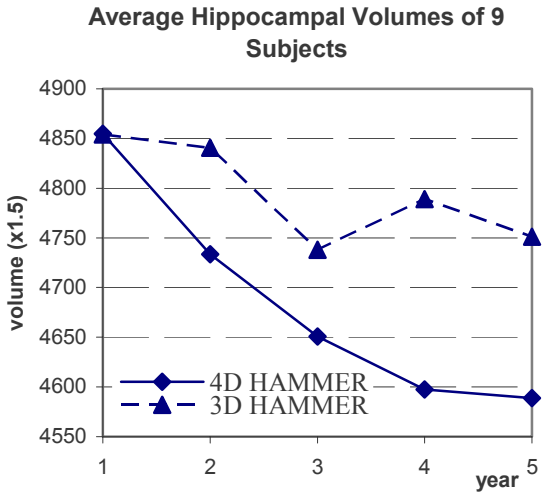
Subject: Modeling and Analysis

Abstract

Introduction:
Longitudinal studies of brain changes require highly accurate segmentation and volumetric measurement of brain structures. Current automatic image segmentation, registration and atlas matching methods are designed for 3D images. The application of these 3D methods independently for each time-point in a longitudinal study typically leads to noisy longitudinal measurements, particularly for small structures such as the hippocampus. In this paper, we propose a fully automatic 4-dimensional atlas warping method that overcomes this limitation by constraining the smoothness in both spatial and temporal domains during the atlas warping procedure, thereby producing the desired smooth and accurate estimations of longitudinal changes. Our approach results in significant improvement over our previously published 3D version of this method, referred to as HAMMER [1-2].

Method:
There are two major steps in our approach. The first step is to rigidly align images of the same subject acquired at different times. The second step is to hierarchically deform the 4D atlas to the 4D subject, by attribute-based matching. An attribute vector of a voxel is determined from image attributes and constitutes the morphological signature of that voxel. It is designed to be as distinctive as possible, thereby reducing ambiguity in detecting anatomical correspondence. The initial deformation of the model to the subject is driven only by the points with distinctive attribute vectors, which minimizes the chance of poor matching. Importantly, the deformation fields are assured to be smooth in both spatial and temporal domains, via appropriate constraints defined in both domains.

Results:
4D HAMMER is used to estimate the longitudinal changes of hippocampal volumes using the MR images of 9 elderly subjects aged 59-78, selected from our ongoing studies in the Baltimore Longitudinal Study of Aging (BLSA). Annual MR images are available for each subject, and the images from the first 5 years are used in this paper. We have labeled hippocampal regions in the model by manual definition of a single template brain. By warping the model to the subject, we can warp the mask of the model hippocampi to each subject, thereby segmenting each subject's hippocampi. The following figure shows the average hippocampal volumes of 9 subjects, estimated by 3D and 4D HAMMER, respectively. Obviously, 3D HAMMER results in noisy longitudinal estimations, while 4D HAMMER produces smooth longitudinal estimations. Importantly, the percentage of hippocampal shrinkage detected during the 5 years is only 2.1% by 3D HAMMER, compared with 5.5% by 4D HAMMER, and 5.7% by manual definition of an experienced rater. This experiment shows that 4D HAMMER is more robust and accurate in estimating longitudinal changes.



Discussion:

We have developed a robust and accurate 4D image warping method, particularly suited to longitudinal morphological measurements. The experimental results show that 4D HAMMER can provide smooth and accurate estimates of longitudinal changes even for small but important structures such as the hippocampus. We are planning to test 4D HAMMER on over 100 subjects and multiple brain regions in the BLSA neuroimaging study, for which MR images have been collected over a 9-year period.

References:

1. D. Shen, C. Davatzikos. *IEEE TMI*, Nov 2002.
2. D. Shen, C. Davatzikos. *NeuroImage*, 18(1): 28-41, Jan 2003.